***The Art of Analog Design***

***Part 3: Monte Carlo Sampling***

In Part 2, we looked at Monte Carlo sampling methods. In Part 3, we will consider what happens once Monte Carlo analysis is complete. Of course, we will need to analyze the results, so let’s look at some of the tools for visualizing what the Monte Carlo analysis is trying to show us about the circuit.

First let’s review the results from the previous blog. The circuit being simulated is a Capacitor D/A Converter, or CAPDAC. The CAPDAC is used in a Successive Approximation ADC to generate the reference levels for comparison. The mismatch of the unit capacitors in the CAPDAC contributes to degradation of the CAPDAC SINAD (Signal-to-Noise and Distortion ratio) and is an important contributor in determining the overall SINAD of the ADC. This CAPDAC is used in a 10 Bit ADC. Based on the error budget for the ADC, if the CAPDAC has a SINAD of 60dB or better we will be able to meet our ADC SINAD target. The CAPDAC SINAD was simulated using Monte Carlo with auto-stop, yield target of 60dB for SINAD, yield of 3σ or greater, confidence level of 90%, and Low Discrepancy Sampling, LDS, method. The simulation required 1755 samples to meet the 90% confidence requirement level.

In the last blog append, we looked at the. The effect of process variation on SINAD distribution was plotted, see figure 1. To help understand the how CAPDAC performance compared to the specification,. The specificationthe pass/fail limits have been overlaid on top of the distribution, green is pass and red is fail.

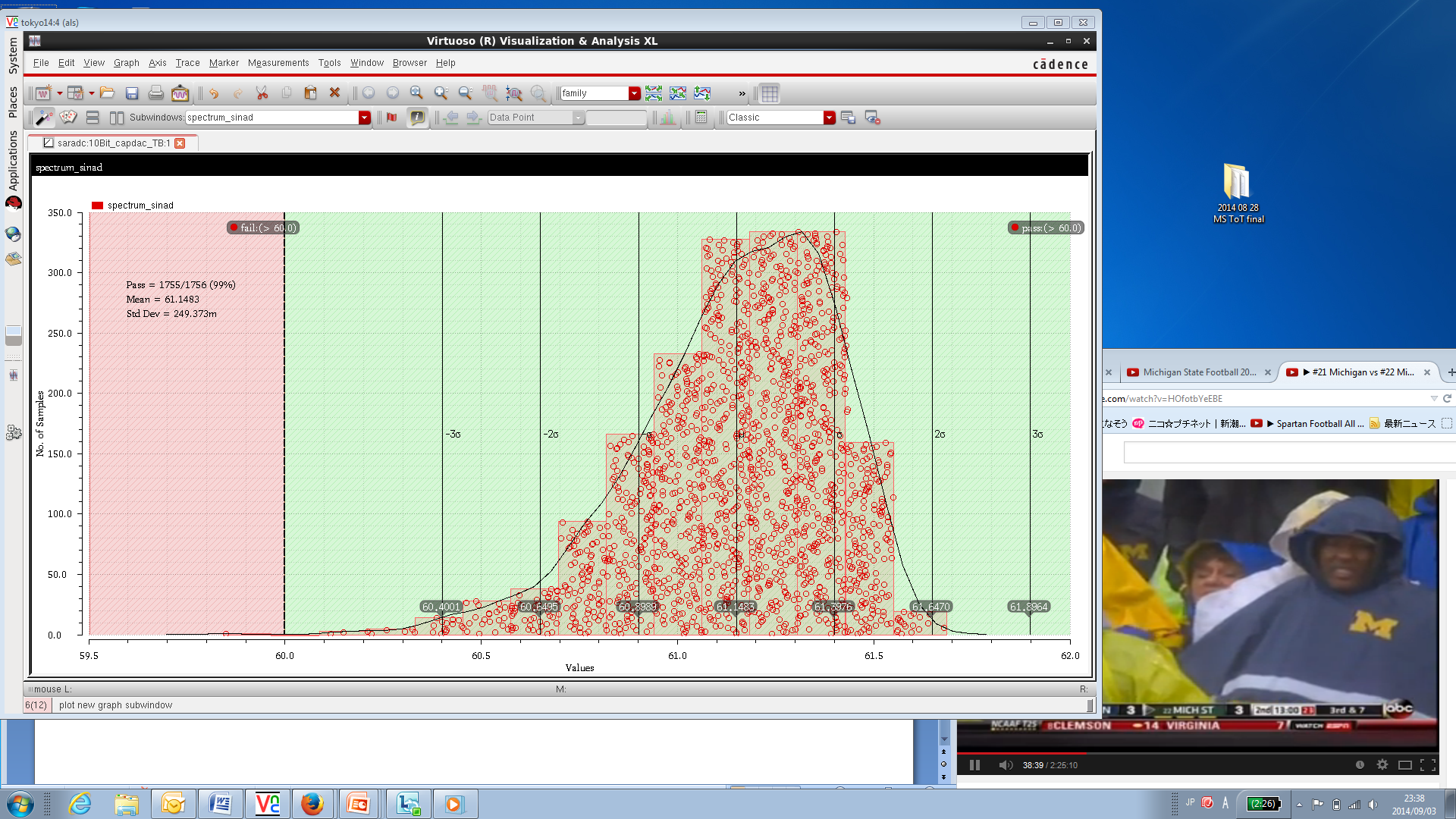


Figure 1: CAPDAC SINAD distribution

The plot also has bars showing the mean value, σ, and the values of standard deviation from -3σto +3σ allowing us to visualize how much margin the CAPDAC has relative to the specification. For the CAPDAC there is almost 2σ close margin between the specification and the upper limit of the specification, -3σ limit, of the distribution.

One observation from looking at the distribution, is that the distribution appears to have a long tail. In statistics, distributions with long tails means that the distribution has a large number of occurrences far from the central part of the distribution. Looking at the distribution, we can see that on the positive side of the distribution, there is only one point that is > +2σ from the mean. While on the negative side of the distribution, there are many data points, < -3σ from the mean. Next, let’s apply another tool, quantile-quantile plotting. The purpose is to test our simulated distribution and is a Normal (or Gaussian) distribution. A quantile-quantile plot is a technique to evaluate if two distributions are the same by plotting their quantiles against each other where the quantiles are points taken at regular intervals from the cumulative distribution function (CDF) of a random variable. The 0-quantile of distribution is the median, it is the value where half the samples in the distribution are higher in value than the median and half of the samples in the distribution are lower in value the median. Since the distribution is skewed, the mean value will not be equal to the median value.

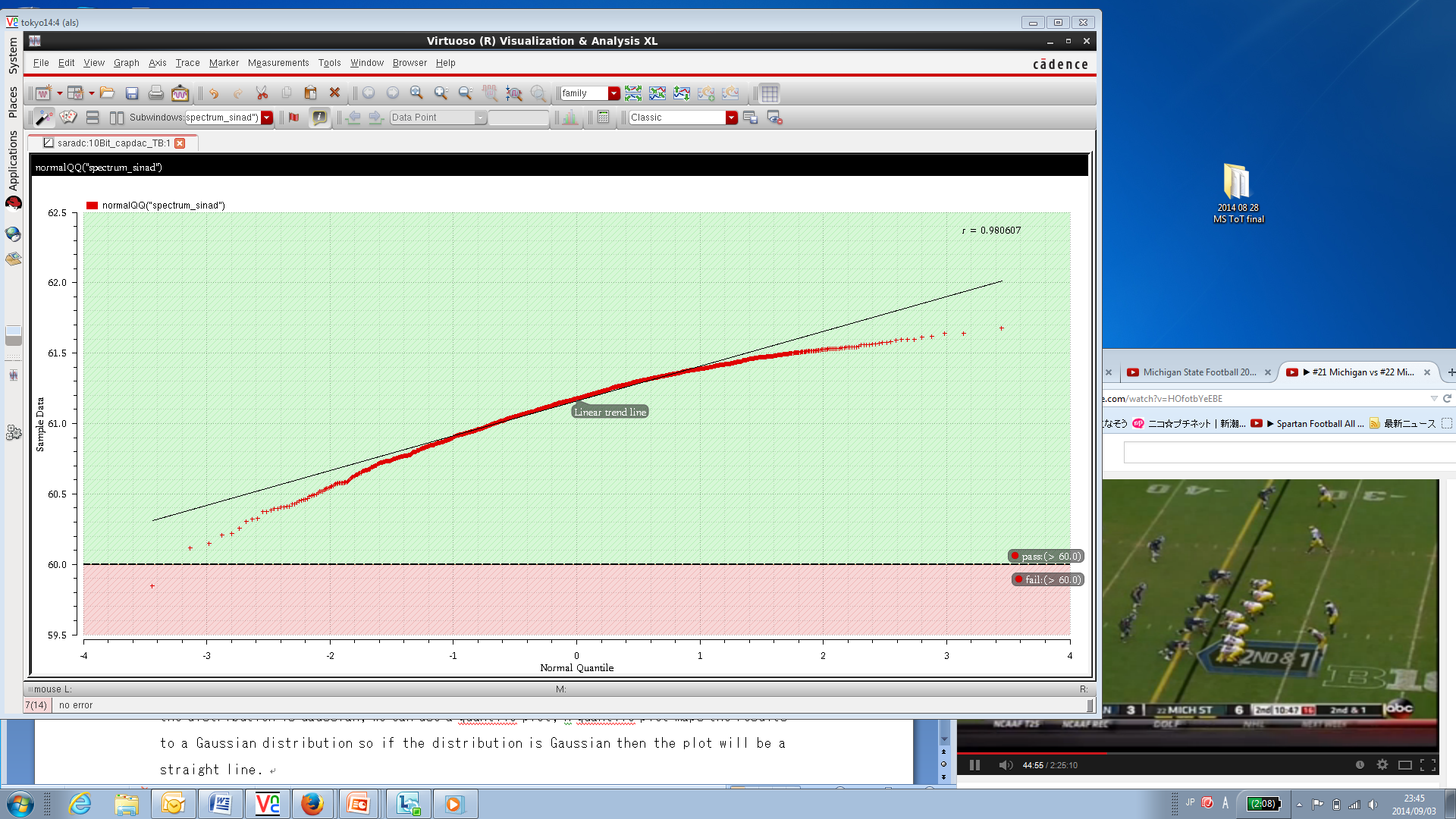


Figure : Quantile-quantile plot for CAPDAC SINAD

If the simulated distribution is a straight line when plotted against the reference distribution, the Normal distribution, then the distributions match and the simulated distribution is Gaussian. As expected, the simulated distribution is not a straight line when plotted against the Normal distribution (see Figure 2). The distribution is only Normal in the region from -1σ to +1σ of standard deviation. Another way to look at the effect of the long tail is to consider how the CAPDAC yield compares to the expected yield of a Normal distribution. For the CAPDAC, there is 1 failure for 1755 samples. The worst-case value of CAPDAC SINAD is 59.85dB, -5.2σ from the mean value. Using the Normal distribution, the expected failure probability for 5σ deviation from the mean value is 1 failure per 3.5 million attempts. The effect of the long tail, non-Normal nature of the distribution, is a significant reduction in the yield compared to the yield when the distribution is a Normal distribution. Using quantile-quantile plots provides a powerful tool for visualizing whether the simulated distribution is a Normal distribution or not.

Next, let’s look at another measurement that is useful for designers. First, let’s determine the process capability index or Cpk value. The Cpk is a statistical measure of process capability which is the ability of a process to produce output within specification limits. For the CAPDAC, the Cpk is one of the outputs in the Virtuoso ADE Assembler results window (see Figure 3). The Cpk can only be output if a specification has been defined.

The Cpk is defined as the ratio of the distance from the mean value to the specification in standard deviations over the distance from the mean value to the actual distribution limit in standard deviation. For the CAPDAC, the numerator is 4.6σ, the distance from the mean value of 61.15dB to 60dB in sigma, see sigma to target. The target yield was 3σ so the denominator is 3σ.

The less precise way to think about Cpk, is to think of it as a measure of design margin. It tells us how much margin we have between the actual limit of the process and the user’s expectation for the process.

To summarize we have looked at two tools for visualizing the results of Monte Carlo analysis and using the tools to identify problems. Plotting distributions allows us to understand how well centered a design is. Quantile plots allow us to look at the distribution and identify if it has a long tail since a long tail can translate into poor yield. And by using Cpk we can quantify how much design margin we have. In the next blog post, we will start to look at what we can do to identify and correct issues.